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9th International Conference of Modeling, Optimization and Simulation - MOSIM'12
June 06-08, 2012 – Bordeaux - France
"Performance, interoperability and safety for sustainable development"

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ABSTRACT: *Home Care Services (HCS) are structures that provide continuous and coordinated health cares at patients' homes. This paper addresses the problem of routing and scheduling caregivers of HCS. Each caregiver visits his patients under time window constraints. Each patient receives multiple care visits and some visits should be synchronized to start at the same time. Two criteria are considered, (1) minimization of the total travel and waiting time of caregivers and (2) minimization of the total completion time of care visits. We model the problem as a Synchronized VRPTW (Vehicle Routing Problem with Time Window) and propose a mixed integer programming model. Numerical results show the impact of the synchronization constraints on the generation of caregivers' tours.*

KEYWORDS: *Resource planning, home health care, mathematical modeling, operation scheduling, VRPTW.*

1 INTRODUCTION

The Home Health Care structures (HCS) have been considered as an efficient solution to the organizational and economic problems of health care systems. These structures provide continuous and coordinated care for patients in their homes. The HCS are defined by Com-Ruelle and Lebrun as *"a mini network in a wider one"* [1] [2], since it requires coordination between actors with varied skills. However it operates itself in a larger network in different modes. These structures were recognized by the French law, i.e. it was defined in the French decree N°92.11.01 of October 1992, as structures that *"ensure, at the patient's home for a limited period, but adaptable to his health condition, continuous and coordinated medical and paramedical care. These treatments differ from those usually provided by the complexity and frequency of activities"*. HCS take an increasingly important place in health care sector. In France the number of HCS has tripled between 1999 and April 2006 from 68 structures to 185 and the number of beds at homecare has increased from 3908 in 1999 to 7355 in April 2006 [2].

Different organizational and clinical decisions arise in HCS operations, such as "coordination" and "synchronization" between various human and/or material resources plus the participation of an important number of actors of different skills [3]. Consequently, tools for design and operations such structures are highly recommended.

In this paper, a mixed integer linear programming-based decision support tool is proposed for routing and scheduling the caregivers' visits for patients. One salient feature is the need to synchronize some visits to the same patient to perform cares that require more than one caregiver. The problem consists of (i) scheduling patients' care activities, and (ii) sequencing caregivers' visits, in order to minimize the caregivers' traveling and waiting time.

The remaining of the paper is organized as follow. Section 2 describes the problem routing and scheduling the caregivers in the HCS and VRPTW problem are presented in section 3. The mathematical formulation with linear programing model is developed in section 4. Section 5 exhibits the numerical results of HCS at two different scenarios. Conclusion and perspectives are put forward in final section.

2 PROBLEM DESCRIPTION

The problem is to determine caregivers' tours, while optimizing the caregivers' travelling and waiting times. The complexity of this problem is due to the various constraints to take into account [2].

Assume that there are *S* caregivers all belong to the *HCS*. Each one follows a route to visit a set of pre-assigned patients. Each patient is available in a given time window. Each visit of caregiver is characterized by a given care time. Each patient needs multiple visits and some visits should be synchronized to start at the same time as they correspond to a care activity that needs several caregivers. As a result, visits of caregivers should be coordinated such that cares of the same patient do not overlap.

Our purpose is to provide a decision tool for routing and scheduling the caregivers in HCS subjected to synchronization constraints. This problem is linked to the Vehicle Routing Problem with Time Windows (VRPTW) [20] with additional synchronization constraints. The VRPTW problem involves fleet of vehicles at warehouse to serve a number of customers, at different locations, with various demands. The objective of the problem is to find routes for vehicles, to satisfy all customers with a minimal travelling time, without violating customers' time windows [21] [22]. The VRPTW is NP-hard problem [23] [24]. To model our problem as a VRPTW, patients are considered as customers, caregivers as vehicles and HCS as warehouse. The goal is to find a set of tours (routes) for each caregiver (vehicle), starting and ending at HCS (warehouse. Each route has its set of predefined patients (customers), and each patient (customer) has his care visits performed by related caregivers (vehicles), providing that the patients' (customers) availabilities are not violated. Some care visits should be synchronized. In this paper, the aim is to minimize the total travelling and waiting times of caregivers.

3 LITERATURE REVIEW

A literature review on the home health care has allowed us to identify relevant issues. Partitioning a geographic territory covered by caregivers is addressed in [4], [5] and [6]. Resource allocation to different geographical areas (or sub-area) is addressed in [7], [8] and [9]. Papers [10], [11], [12] and [13], address the application of information and communication technologies in home care services. In the following paragraphs we focus on planning and scheduling of caregivers.

Nurses' tour problem in homecare was treated in [14] using VRPTW. The problem is to find an optimal schedule, such that each nurse leaves from home, visits a set of patients within their time windows, takes a lunch break, and returns home, all within the nurses' time window, while minimizing both, over time for full-time nurses and part-time nurses.

A decision support tool was presented in [15] to construct the nurses' tour schedules taking into account patients' availabilities, requirements, and nurses' availabilities.

In [16] a tool to plan the nurses' tours in homecare was developed using the MILP by taking into account different constraints, as patients' availabilities, lunch break for nurses and the travelling times. The objective function was "minimizing the total travelling distance".

A novel application for scheduling home caregivers was presented in [17]. The model was based on meta-heuristic approach called Particle Swarm Optimization (PSO). The tool is applied to a genuine situation arising in UK. The proposed tool optimizes the travelling distance, providing that the capacity and time windows constraints of services are not violated.

A multi criteria method for the home health care problem was proposed in [3] by combining linear programming, constraint programming, and meta-heuristics (tabu search). Multiple constraints as patients' satisfaction, nurses' qualifications, time windows, were taken into account, while minimizing the travelling costs.

In [18], a novel approach based on VRPTW and MILP, was presented for planning and scheduling caregivers' visits in a home care service. New temporal constraint was added to the proposed model, to define some given partial order between cares visits, this order is called "the coordination" between caregivers. The optimized criterion is the caregivers' travelling and waiting times.

The problem of scheduling caregivers' activities was resolved in [19] using RCPSP (Resource-Constrained Project Scheduling Problem) and linear programming, while taking into account coordination between care activities (imposed given partial order on the care activities) and real life constraints. The criterion was patients' waited time between care activities.

Eveborn et al [29] have proposed a tool based on heuristics for both patients allocation to care provider and visits' schedules. They incorporate some constraints, and their objective was to reduce the transportation time and increase the patients' satisfactions. Each visit has particular tasks to be performed (cleaning, washing), in addition to nursing activities. Each staff member has skills and each patient is visited by the same care provider.

In [28], authors propose an approach for determining the caregivers' tours in a given working day, in order to optimize multiple criteria, i.e. optimizing caregivers' tours and limiting patients' waited time between two different visits. The coordination between care visits (the predefined order between care visits) was taken into account. Authors proposed two mixed integer programming (MILP) models, each corresponding to a scheduling strategy.

Throughout this review, we demonstrated works concerning nurses' scheduling and planning activities. We noticed that existing works do not address the synchronization between different providers (i.e. performing care visits at the same time). Table 1 provides a comparison between existing works.

This paper is also related to the literature on VRPTW. Especially a mathematical programming model for both vehicle routing plus scheduling under time windows and additional synchronization constraints between several vehicles that are addressed in [27]. Authors indicate that the proposed approach may be applicable in different domains (airline scheduling, forest operations …). The vehicles in the proposed approach start each tour from a warehouse, to visit the pre-allocated customers. At the end of the tour, vehicles return to the warehouse. The shared customers are only those who need synchronized visits. The proposed tool is not able to resolve problem if a customer need multiple visits within synchronization. This case is needed in our HCS problem where patient needs several care activities per day. We conclude that the recent approach may be applicable to the routing and scheduling of caregivers in home care, but not in the general case, i.e. this method is not appropriate if patients need shared and multiple visits per day. The goal of this paper is to develop a novel approach for planning and scheduling the caregivers' visits. A novel property that allows realizing the synchronization process is added to the proposed model. In the next section, we present the mathematical formulation of the problem.

	Optimized criterion	Patients' availabilities	Shared patients	Coordination	Multiple visits for patients per day	Synchro-nization	Exact methods
[14]	Costs of working hours	X					X
[15]	Travel duration		X		X		X
[3]	Balancing work load + Travel duration	X	X		X		
[16]	Travel duration	X	X				X
[17]	Travel duration	X	X		X		
[29]	Travel duration	X	X		X		
[18]	(i) travelled + waited durations (ii) caregivers' worked durations	X	X	X	X		X
[19]	Patients' waited time.	X	X	X	X		X
[28]	(i) the visits' completion times (ii) the patients' waited time	X	X	X	X		X
The proposed approach	**(i) the caregivers' traveling and waiting times (ii) the visits' completion times**	X	X		X	X	X

Table 1: Comparison between methods developed for home care.

4 MATHEMATICAL FORMULATION

The problem can be described as VRPTW subjected to synchronized constraints denoted as S-VRPTW. Given a set of patients, a set of caregivers and HCS, the goal is to find a route for each caregiver, starting and ending at the HCS and visiting a given set of patients. Each patient may be cared by several caregivers, within their availabilities. Some patients' visits need to be synchronized, i.e. cares are achieved at a same time by two caregivers.

4.1 Assumptions

We assume that, each patient receives a caregiver at most once a day, within his/her time window. Each care visit has a given time duration, that depends of the care to provide. We assume also that the patients are allocated to caregivers, which represents another problem that has a set of constraints and objectives. Each caregiver starts and ends the tour at the HCS (the HCS is considered as a dummy patient). Some visits for the same patients need to be synchronized. Synchronized visits have same duration, i.e. start and end at the same time.

4.2 Parameters and notations

- N: set of patients,
- S: set of caregivers,
- td_{ij}: travel time from patient i to patient j,
- p_{is}: care duration to patient i by caregiver s,
- $r_i < d_i$: availability time window of patient i,
- N_s: set of patients to be visited by caregiver s,
- S_i: set of caregivers that will visit patient i,
- K_i: number of synchronized visits for patient i,
- $S_i = \bigcup_{k=1}^{K_i} S_{ik}$: partition of the set of caregivers of patient i in sets of visits to be synchronized. Of course, $S_{ik} \bigcap S_{ik'} = \varnothing$
- M: a large constant.

By convention, patient *#1* represents the start at HCS and patient $n = |N|$ the end at HCS with $S_i = S_n = N$, $r_1 = r_n = 0$, $d_1 = d_n = T$, $p_{1s} = p_{ns} = 0$, while 0 and T are respectively, begin and end of the working day.

4.3 Decision variables

- x_{ijs} = 0/1 such that, x_{ijs} = 1 if caregiver s visits patient i strictly before patient j, x_{ijs} = 0 otherwise,
- z_{isr} = 0/1 such that z_{isr} = 1 if patient i is visited by caregiver s just before caregiver r, otherwise z_{isr} = 0,
- t_{is}, C_{is}: starting time and completion time of patient i care by caregiver s,
- $arriv_{is}$: arrival time of caregiver s at patient i's home,
- $Wait_{is}$: witing time of caregiver s before caring patient i,
- u_{is}: order of visit of patient i in the tour of caregiver s.

4.4 Linear programming model

Two objective functions (1) and (2) are considered:

$$Min\sum_{s\in S}\sum_{i\in N_s} wait_{is} + \sum_{s\in S}\sum_{i\in N_s}\sum_{j\in N_s} td_{ij} x_{ijs} \quad (1)$$

$$Min\sum_{s\in S}\sum_{i\in N_s} C_{is} \quad (2)$$

Such that:

$$wait_{is} = t_{is} - arriv_{is} \qquad \forall s\in S, \forall i\in N_s \quad (3)$$

$$t_{is} + p_{is} = C_{is} \qquad \forall s\in S, \forall i\in N_s \quad (4)$$

The routing and scheduling constraints are modeled as follows:

$$\sum_{j\in N_s} x_{ijs} = 1 \qquad \forall s\in S, \forall i\in N_s - \{1\} \quad (5)$$

$$\sum_{i\in N_s} x_{ijs} = 1 \qquad \forall s\in S, \forall j\in N_s - \{n\} \quad (6)$$

$$x_{iis} = 0 \qquad \forall s\in S, \forall i\in N_s \quad (7)$$

Constraints (5) - (7) are the modified constraints of classical VRPTW problem [2] [25] [18]. They ensure sequencing the caregivers' visits. Constraints (8) are timing constraints of all patients in the tour of a caregiver:

$$t_{is} + p_{is} + td_{ij} - M\left(1 - x_{ijs}\right) \le arriv_{js} \qquad \forall s\in S, \forall i,j\in N_s \quad (8)$$

Constraints (9) - (13) ensure sequencing the multiple care visits performed for the same patient:

$$\sum_{s\in S_i} z_{isr} \le 1 \qquad \forall i\in N, \forall r\in S_i \quad (9)$$

$$\sum_{r\in S_i} z_{isr} \le 1 \qquad \forall i\in N, \forall s\in S_i \quad (10)$$

$$\sum_{s\in S}\sum_{r\in S} z_{isr} = |S_i| - 1 \qquad \forall i\in N \quad (11)$$

$$z_{iss} = 0 \qquad \forall i\in N, \forall s\in S_i \quad (12)$$

$$t_{is} + p_{is} - M(1 - z_{isr}) \le t_{ir} \qquad \forall i\in N, s\in S_{ik}, r\in S_{ik'}, k\ne k' \quad (13)$$

The synchronization constraints are as follows:

$$t_{is} = t_{ir} \qquad \forall i\in N, \forall s,r\in S_{ik} \quad (14)$$

Constraints (15) - (18) ensure the availability of patients and working time of caregivers:

$$t_{1s} = 0 \qquad \forall s\in S \quad (15)$$

$$C_{ns} \le d_n \qquad \forall s\in S \quad (16)$$

$$t_{is} \ge r_i \qquad \forall i\in N, \forall s\in S_i \quad (17)$$

$$t_{is} + p_{is} \le d_i \qquad \forall i\in N, \forall s\in S_i \quad (18)$$

The sub-tours of each caregiver are eliminated by constraints (19) - (21) derived from Desrocher and Laporte's sub-tour elimination [26], and modified in [18].

$$u_{is} - u_{js} + (N-1)x_{ijs} + (N-3)x_{jis} \le N-2 \qquad \forall s\in S, \forall i,j\in N_s \quad (19)$$

$$u_{1s} = 1 \qquad \forall s\in S \quad (20)$$

$$u_{ns} = |N_s| \qquad \forall s\in S \quad (21)$$

$$u_{is} \le |N_s| \qquad \forall s\in S, \forall i\in N_s \quad (22)$$

The equations (22) and (23) are binary or non-negativity constraints:

$$t_{is}, wait_{is} \ge 0, u_{is} \in IN \quad (23)$$

$$x_{ijs}, z_{isr} \in \{0,1\} \quad (24)$$

5 NUMERICAL RESULTS

The model is solved, using the *LINGO_11.0* solver from *LINDO SYSTEMS INC*. In this part, the aim is to present results based on an example of 4 caregivers and 15 patients (patient *#1* represents the start at HCS and patient n = 15 the end at HCS). Tests are varied using two scenarios based on patients' locations and both objective functions (1) and (2).

- *The first scenario*: all patients live the same district and the travelling times are between 15 to 40 minutes.
- *Second scenario*: the deserved area is divided into two different districts, with travelling times in the same district between 17 and 25 minutes, and between 40 to 60 minutes between different districts, such that:

- *1st district*: patients {#1, #2, #3, #4, #5, #6, #7, #15}.
- *2nd district*: patients {#8, #9, #10, #11, #12, #13, #14}.

5.1 The instances

The model was tested on an example of 15 patients, i.e. the set N is {1...15} patients. In this example each one of the patients {*#2, #6, #11, #14*} requires 2 synchronized visits (we have considered the same care durations for the synchronized visits for each patient). The example considers also 4 caregivers with shared patients. The assignment of patients to caregivers is defined in patients' care protocol, conceived by the care team of the *HCS*.

The patients requiring synchronized visits are:

- Patient #2: Caregivers 3 and 4.
- Patient #6: Caregivers 2 and 3.
- Patient #11: Caregivers 1 and 2.
- Patient #14: Caregivers 1 and 4.

The patients' availabilities may be the whole day (i.e. [1,480]), in the morning (i.e. [1, 240]) or at the afternoon (i.e. [240, 480]). The patients' availabilities in our case are:

- Day: patients {#1, #3, #4, #5, #10, #14, #15}.
- Morning: patients {#2, #8, #9, #13}.
- Afternoon: patients {#6, #7, #11, #12}.

Table 2 displays the allocation of patients to caregivers and care durations for each patient:

CG* 1		CG 2		CG 3		CG 4	
Pat	p_{i1}	Pat	p_{i2}	Pat	p_{i3}	Pat	p_{i4}
#1	0	#1	0	#1	0	#1	0
#3	35	#2	25	#2	20	#2	20
#5	15	#4	20	#3	15	#5	30
#8	30	#6	35	#4	25	#6	20
#9	25	#7	25	#5	35	#7	15
#10	35	#8	20	#6	35	#9	20
#11	25	#11	25	#8	30	#10	35
#13	15	#12	25	#11	25	#13	35
#14	30	#14	30	#13	25	#14	30
#15	0	#15	0	#15	0	#15	0

* CG = Caregiver

Table 2: Patients' allocation to caregivers and care durations

The *MILP* model was tested using both scenarios and objective functions. In order to avoid excessive computation time to achieve the optimal solution, we have studied the evolution of both objective functions versus time, and we have noticed that the optimality rate approaches "96%", in 20 minutes of computing time, which presents a satisfactory feasible solution, i.e. the gap between the optimal and the feasible solution obtained in 20 minutes of calculating time is 4%.

5.2 Results

Table 3 illustrates results obtained when model is simulated using the first scenario (i.e. the deserved area is composed from one district) and both objective functions. The caregivers' tours and the visits times are represented below. In this scenario, the patients' availabilities and the limits of the working day are respected. On other side, the synchronized visits (i.e. caregivers 1 and 2 to care patients #2, caregivers 2 and 3 to care patient #11, caregivers 3 and 4 to care patient #6 and caregivers 1 and 4 to care patient #14) were respected (synchronized visits are highlighted in same color in table 3).

In this case the patients are located in the same district, the caregivers' tours are generated by choosing the minimal waiting and traveling times, when using the first objective function. The goal set out by developing the second objective function (minimizing the caregivers' completion care visits) was also minimizing the caregivers' traveling and waiting times, by compacting the care visits, providing that the patients' availabilities and the limits of the working day are not violated.

Objective function 1											
Caregiver 1			Caregiver 2			Caregiver 3			Caregiver 4		
Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}
#1 (HCS)	1	1	#1 (HCS)	1	1	#1 (HCS)	1	1	#1 (HCS)	1	1
#10	21	21	#8	26	26	#2	19	19	#2	19	19
#13	73	73	#4	71	71	#3	65	65	#10	56	56
#5	108	108	#2	116	142	#8	110	110	#9	109	109
#8	143	143	#14	192	192	#5	160	160	#13	149	149
#9	190	190	#11	240	240	#13	215	215	#5	204	204
#11	235	240	#7	283	283	#11	265	265	#7	251	251
#14	283	296	#12	325	325	#4	315	328	#14	296	296
#3	344	344	#6	368	371	#6	371	371	#6	351	351
Objective function 2											
Caregiver 1			Caregiver 2			Caregiver 3			Caregiver 4		
Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}
#1 (HCS)	1	1	#1 (HCS)	1	1	#1 (HCS)	1	1	#1 (HCS)	1	1
#10	21	21	#8	26	26	#13	21	21	#9	19	19
#5	73	73	#2	76	76	#8	63	63	#13	59	59
#13	108	108	#4	126	126	#5	113	113	#10	111	111
#9	143	143	#14	176	176	#2	168	168	#2	163	168
#8	185	185	#7	236	240	#3	208	208	#14	213	235
#14	235	235	#12	282	282	#4	253	253	#7	295	295
#3	283	283	#6	325	325	#6	296	325	#5	327	327
#11	368	380	#11	380	380	#11	380	405	#6	382	382

Table 3: The caregivers' tours in the first scenario

On other side the patients' sequencing is realized assuring that the environments' constraints are not violated. The objective functions are sufficiently optimized (96% of optimality). We noticed from table 3 that the tours obtained for all caregivers are different while using both objective functions, i.e. different patients scheduling.

Care times are generated taking into account the synchronized visits for patients' #2, #6, #11 and #14. Care visits for both patients must begin at the same time. Assuming that the care time of the patient *#i* cared by the caregiver "CG_s" is decided at time t_{is}. This decision will consequently block the care time of the same patient *#i* in the tour of other caregiver "CG_r" at the same time where $t_{ir} = t_{is}$. Blocking the care time in this way means that all care times have to be different from t_{is} and t_{ir}, respectively in the tours of caregivers "CG_s" and "CG_r". Thus the synchronization decision impacts on the remaining decisions, i.e. care times for the remaining patients visited by caregivers.

In the simulated example (table 3), we remark while using the first objective function that, the decision on care time for patient *#2* cared by caregiver 3 was "$t_{2\ 3} = 19$". This decision consequently blocks the care time of the same patient (*#2)* in the tour of caregiver 4 at the same time "$t_{2\ 4} = 19$". This situation represents a hard constraint that impacts the generation of the remaining visits for caregivers CG_2 and CG_3. Thus synchronization is a "hard" constraint that has an immediate impact on the decision concerning the caregivers' tours, and so on the patients' scheduling.

We conclude from this scenario that, the tours generation was efficiently generated, i.e. the environment's constraints were respected and the caregivers' traveling and waiting times were sufficiently optimized. Optimizing these criterions was realized using two distinct objective functions. In a next part a comparative work between both objective functions, in term of travelling and waiting times will be realized. Moreover the tours' generation is mainly impacted by the synchronized visits which represent "hard" constraint.

Table 4 illustrates the results of second scenario (i.e. the deserved area is divided on two districts) using both objective functions. We remark, from the patients' scheduling and the visiting times represented above, that, the working day and the patients' availabilities are respected. The synchronized visits are also respected, i.e. the care times for the all patients needing two different caregivers at the same time were equal (synchronized visits are highlighted in same color in table 4).

Objective function 1											
Caregiver 1			Caregiver 2			Caregiver 3			Caregiver 4		
Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}
#1 (HCS)	1	1	#1 (HCS)	1	1	#1 (HCS)	1	1	#1 (HCS)	1	1
#8	41	44	#2	19	39	#2	19	19	#2	19	19
#10	92	92	#4	82	83	#4	57	58	#9	79	79
#9	144	144	#8	153	153	#13	133	154	#13	119	119
#13	189	189	#14	193	193	#8	204	204	#10	172	172
#14	224	224	#12	240	240	#11	254	254	#14	224	224
#11	271	285	#11	285	285	#5	324	324	#5	294	294
#3	355	355	#6	355	376	#6	376	376	#6	341	341
#5	408	408	#7	431	431	#3	428	428	#7	381	381
Objective function 2											
Caregiver 1			Caregiver 2			Caregiver 3			Caregiver 4		
Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}	Scheduled patients	$arriv_{ps}$	t_{ps}
#1 (HCS)	1	1	#1 (HCS)	1	1	#1 (HCS)	1	1	#1 (HCS)	1	1
#3	21	21	#4	19	19	#2	19	19	#2	19	19
#13	96	96	#2	57	57	#4	57	57	#5	59	59
#8	136	136	#14	137	137	#3	102	102	#9	144	144
#9	183	183	#8	187	187	#13	157	157	#13	184	184
#11	228	240	#11	227	240	#8	207	207	#10	237	237
#14	282	289	#12	285	285	#11	257	265	#14	289	289
#10	336	336	#7	365	379	#5	335	335	#7	364	364
#5	431	431	#6	424	424	#6	387	424	#6	399	399

Table 4: The caregivers' tours in the second scenario

In this scenario patients are located in two distinct districts. Using the first objective function leads to generate the caregivers' tours by choosing the minimal waiting and traveling times at the same and between different districts. For the same purpose we have developed the second objective function, which allow compacting the caregivers' care visits (minimizing the caregivers' completion care visits), while taking into account the patients' availabilities and limits of working day. This situation is more complex than the first one. This complexity is due to patients' availabilities, districting of the deserved area to multiple districts and synchronization constraints. The results obtained in this scenario show that the proposed approach is efficient in managing such complex situation.

The patients' sequencing for each caregiver is realized providing that the environment's constraints are not violated and the optimality rate for both objective functions was nearly 96%, i.e. the feasible solution found was sufficient. We noticed from each scenario in table 4 that all the tours obtained for each caregiver using both objective functions are different, i.e. different patients' sequencing for each caregiver. The patients' sequencing returned by the model allows meeting the environment's constraints, and satisfying the caregivers' and the *HCS* by optimizing the caregivers' traveling times between patients' at same district and between different districts and also their waiting times. A comparative work in term of traveling and waiting times is realized in the next part. The comparative work allows us to nominate the most efficient objective function, in term of caregivers' traveling and waiting time.

The method used to realize the synchronized visits for patients #2, #6, #11 and #14 is the same as in the first scenario, i.e. forcing the care time for patient needing visits by two caregivers to be equal. i.e. the care time of patient *#i* cared by caregiver *"CG_r"* is forced to be equal to his care time by caregiver *"CG_s"*. In simulated model (table 4), the decision on care time for patient *#6* cared by caregiver 2 was "$t_{6\ 2} = 424$" using the second objective function, this will consequently set his care time by caregiver 3 at the same value "$t_{16\ 3} = 424$". We conclude from this part that the synchronization constraint has an immediate impact on the generation of caregivers' tours, i.e. the patients' scheduling for each caregiver.

We conclude from this scenario that, tours generation depends on the patients' availabilities, travel durations between patients at the same district and traveling time between different districts. The tours generation is also impacted by constraints that allow realizing the synchronized visits. On other side the proposed tool uses an efficient strategy to manage the complexity of environment's constraints, i.e. the traveling between districts and the patients' availabilities.

From these tests (Scenario 1 and 2) it is noted that, the proposed model is efficient while managing the complex situations, i.e. the districting of the deserved area, the patients' availabilities and the synchronized visits. In this case, the proposed tool uses an efficient strategy to schedule patients for each caregiver, whatever the objective function. This strategy allows choosing the best schedule in both districts, which leads to minimal traveling and waiting times between patients, providing that the patients' availabilities are respected. The generated schedule must also take into account the traveling time between the different districts. It is also noted that synchronization of care visits has impact the generation of caregivers' tours.

5.2.1 Analysis of the waiting times for the synchronized caregivers

Table 6 illustrates the waiting times of the synchronized caregivers, i.e. the waiting time of the caregivers that need to be synchronized to care same patient.

From table 6, we remark that in many situations the waiting time for one of both caregivers is not distributed in an equitable manner, i.e.one of the caregivers may wait a long time, unlike the second one. For example, in the first situation using the second objective function, the waiting time of the caregiver 2 before caring patient #6 is equal to 0, while it is equal to 29 for caregiver 3. The waiting time of caregiver 1 is equal to 14 in the second situation using the first objective function, and it is equal to 0 for caregiver 2.

	Patients needing synchronized visits	Objective function (1)		Objective function (2)	
		Waiting time for synchronized caregivers		Waiting time for synchronized caregivers	
Scenario 1 (One district)	*#2*	CG3 = 0	CG4 = 0	CG3 = 0	CG4 = 5
	#6	CG2 = 3	CG3 = 0	CG2 = 0	CG3 = 29
	#11	CG1 = 5	CG2 = 0	CG1 = 12	CG2 = 0
	#14	CG1 = 13	CG4 = 0	CG1 = 0	CG4 = 22
Scenario 2 (Two districts)	*#2*	CG3 = 0	CG4 = 0	CG3 = 0	CG4 = 0
	#6	CG2 = 21	CG3 = 0	CG2 = 0	CG3 = 37
	#11	CG1 = 14	CG2 = 0	CG1 = 12	CG2 = 13
	#14	CG1 = 0	CG4 = 0	CG1 = 7	CG4 = 0

Table 6: The waiting times for the synchronized caregivers

We note from the results presented in table 6 that, three situation may cause the waiting times for one or both caregivers. Firstly, while both caregivers' arrive to the patients' home prior to their window of availability, this can lead to a waiting time for both caregivers. In the second scenario while using the second objective function, we cite the waiting times of caregivers 1 were equal to 12 and caregiver's 2 waiting time was equal to 13, to realize the synchronized care visit to patient #11, such as the caregiver 1 arrives to patients' #11 home at 228 and caregiver 2 arrives at 227, while patient is available for the afternoon, i.e. his window of availability is [240, 480].

Second the waiting time may be caused by the arrival of first caregiver prior to the other. From the simulated example in the first scenario and the second objective function, the waiting time of caregiver 4 was 22 and the waiting time of the caregiver 1 was equal to 0. This situation was caused by the arrival time of caregiver 4 prior to caregiver 1, i.e. the arrival time of caregiver 4 to the patient #14 is "$arriv_{14\ 4} = 213$", while the arrival time of caregiver 2 and the care time of patient #14 by both caregiver is "$arriv_{14\ 1} = t_{14\ 1} = t_{14\ 4} = 235$".

Finally the waiting times of the synchronized caregivers may be caused by the arrival of one or both caregivers to the patient, before the end of a care visit that is placed before the synchronized one. This situation didn't occur in our simulated example. On other side we noticed that the waiting times of the synchronized caregivers are better optimized using first objective function.

We conclude from this analysis that, the synchronized visits may impact the caregivers' waiting times. On other side this analysis has proved the limits of the proposed approach while satisfy all the synchronized caregivers. The arrival of both caregivers at the same time or with a small amount of time, would lead to satisfying all the caregivers by reducing their waiting time before caring patient. In the next section, a comparative work between both objective functions is realized.

5.2.2 Comparative work between objective functions

The objective functions are formalized in different ways. The first one minimizes the sum of travelled and waited times. The goal of the second is to compact all care visits, by minimizing the sum of caregivers' completion visits' times. Table 5 illustrates comparative results between objective functions, using both scenarios.

	Caregivers	Objective function (1)		Objective function (2)	
		Travelling time	Waiting time	Travelling time	Waiting time
Scenario 1 (One district)	*CG 1*	195	18	227	12
	CG 2	191	29	240	4
	CG 3	196	19	210	54
	CG 4	185	0	189	27
Scenario 2 (Two districts)	*CG 1*	220	17	241	19
	CG 2	225	42	246	27
	CG 3	230	22	223	45
	CG 4	207	0	233	0

Table 5: Comparative work between objective functions

The caregivers' waiting times are the amounts of time waited before caring any patient, including the patients needing synchronized visits. These waiting times are due to the arrival of the caregivers at the patient's home prior to his/her time window of availability, such that the patients' availabilities are varied between all the working day, the morning and the afternoon. Experimental results show that, minimizing explicitly the sum of travelling and waiting times (1st objective function), or minimizing the caregivers' completion visits' times (2nd objective function), leads to different travelled and waited times. The total sum of travelling and waiting times for all caregivers using first objective function is 833 minutes, and 963 using the second one at 1st scenario (one district). In this scenario, the minimal sum of travelled and waited times are equal to 213 and the maximal one is 220 using the first objective function, thus the sum of travelling and waiting times is included between 216 and 264 using the second.

In the 2nd scenario (two districts), using the first objective function, the total sum of travelling and waiting times for all caregivers is 963 minutes, it is included between 207 and 267 for each caregiver. Using the second objective function leads to a total sum of the caregivers' travelling and waiting times equal to 1034, while it is included between 233 and 273 for each caregiver.

We conclude from this comparative work that the first objective function is more efficient than the second one while minimizing the caregivers' traveling and the waiting times.

6 CONCLUSION AND PERESPECTIVES

The work presented in this paper has dealt with the caregivers' tours problem, while taking into account an important criterion highly needed in homecare process, namely synchronization between multiple caregivers (or care visits) to care the same patient. The caregivers tours problem is due to the costs of caregivers' travelling and waiting times. Minimizing these costs is linked to good planning.

We have oriented our method to satisfy the caregivers by reducing their travelling and waiting times. For that we have proposed two objective functions, such that (i) the first one allows minimizing the sum of the caregivers' travelling and waiting times, and (ii) the second one allows minimizing the visits' completion times. Providing that, the patients' availabilities and the environments' constraints are not violated. The proposed approach was tested using different scenarios linked to the patients' location, i.e. patients are grouped in the same district, or patients are partitioned on two different districts. On other side, the patients' availabilities were varied between the morning, the afternoon and the day. We have showed by numerical results that the generation of the caregivers' tours is highly impacted by the synchronization constraints. This is due to imposing a single starting time for all caregivers that must realize the same care for a patient. In addition we have compared between the proposed objective functions in term of caregivers' travelling and waiting times, and we have noticed from this comparative work that using an objective function that minimizes the total sum of travelling and waiting times, is more efficient compared to minimizing the visits' completion times.

Besides, this work ameliorated to limit the waiting time of caregivers, before caring a patient that need synchronized visits. On another side this work can be extended to take into account both the synchronization and the coordination constraints (studied in our previous works) at the same time. To satisfy all the care actors it will be more interesting to optimize patients' waiting times between different visits and at the same time optimizing the caregivers' travelling and waiting times. It's clear that the home care process is subject to uncertainties which may be in the caregivers' traveled time, the availability of material resources or care durations …etc. so it will be interesting to take into account these real life constraints.

ACKNOWLEDGMENTS

This work is achieved under the project OSAD (Organisation des Soins A Domicile), financed by the Rhône-Alpes region - France.

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